Photochemically Etched Construction Technology Developed for Digital Xenon Feed Systems

Electric propulsion systems are quickly emerging as attractive options for primary propulsion in low Earth orbit, in geosynchronous orbit, and on interplanetary spacecraft. The driving force behind the acceptance of these systems is the substantial reduction in the propellant mass that can be realized. Unfortunately, system designers are often forced to utilize components designed for chemical propellants in their electric systems. Although functionally acceptable, these relatively large, heavy components are designed for the higher pressures and mass flow rates required by chemical systems. To fully realize the benefits of electric propulsion, researchers must develop components that are optimized for the low flow rates, critical leakage needs, low pressures, and limited budgets of these emerging systems.

Starting in 2001, a team led by VACCO Aerospace Products was selected by NASA under an Advanced Cross-Enterprise Technology Development Program to conduct a project entitled “Photo-Chemically Etched Construction Technology for Digital Xenon Feed Systems.” This program consists of application-engineering xenon pressure- and flow-control modules using a proprietary VACCO technology called Chemically Etched Miniature Systems (ChEMS, VACCO Industries, Inc., Space Products, South El Monte, CA), which is based on VACCO’s extensive in-house experience in the precision chemical etching of metals and plastics.

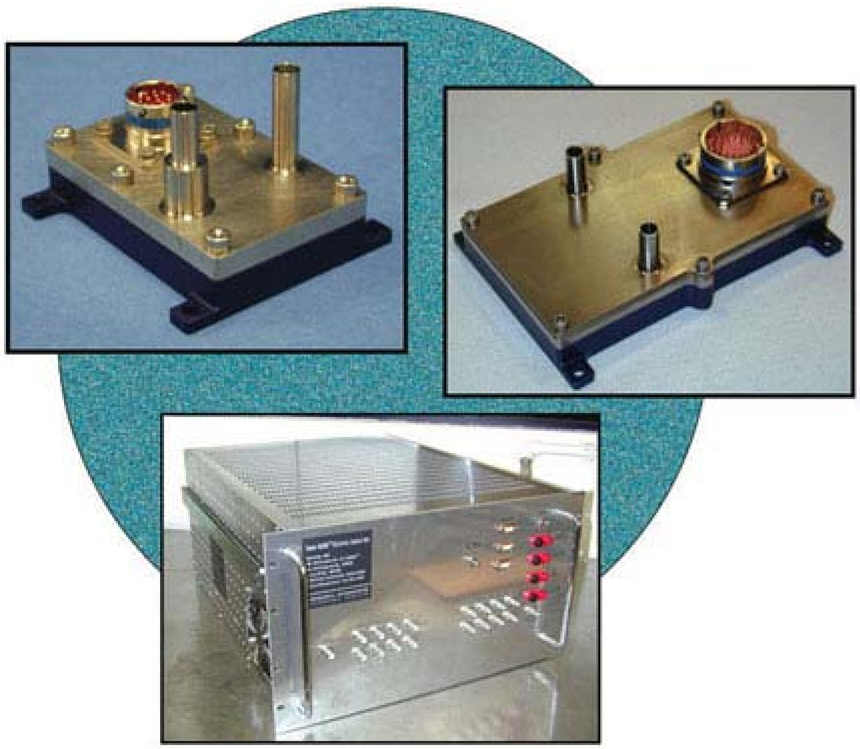
ChEMS modules consist of multiple layers of etched metal or plastic sheets that, when stacked and bonded together, form an assembly of all of the components and their interconnecting flow paths. These modules can alter pressure and flow-rate set points as well as compensate for changing inlet pressure and temperature conditions. The size and mass of complex modules is drastically reduced through the fabrication of components and interconnecting features that are an order of magnitude smaller and lighter than components made using traditional machining techniques.

Several functional features enable the ChEMS-based xenon feed system (XFS) to be ideally suited to the control of xenon to the thrusters in electric propulsion systems. These include

- **Variable set point**.--The XFS mass flow rate and pressure set points are variable and can be changed at the control computer.
- **Pressure and temperature compensation**.--Xenon mass flow can be accurately maintained over a wide band of propellant temperatures and pressures.
- **Reliability**.--The only moving parts in the XFS are the suspended armatures for the 12 valves. The armatures are welded to S-springs that guide them so that they

move without sliding against adjacent parts. To preclude failure, researchers designed the S-springs for low stress and high fatigue life.

- **Failure tolerance**.--The XFS can function even after sustaining two isolation valve failures. In addition, failure of one or more of the valves in the digital flow-control array will degrade flow-control accuracy and engine performance, but it will not cause loss of the engine.



Critical components of a xenon feed system (XFS) developed by VACCO. Top left: Pressure-control module that provided variable-pressure control. Top right: Flow-control module that enabled high-fidelity regulation of the xenon flow to the thruster. Bottom: Electronic-control unit that was the interface to a computer where the XFS control software was operated.

This 3-year contract led to the successful development of a single-line xenon feed system. The major elements of the feed system, shown in the preceding photograph, include the variable-pressure-control module, the digital flow-control module, and the electronic-control unit (designed and fabricated by Aerojet RRC (Redmond, WA)) to operate these modules, which interfaces the XFS to the control computer. The initial operating targets for the flow- and pressure-control modules were selected in discussions with the NASA Glenn Research Center and the Jet Propulsion Laboratory, at which time it was decided to size the flow control for use with a multikilowatt Hall effect thruster.

Fabrication of the pressure-control module and a first-generation electronic-control unit were completed in 2002. After a series of sealing issues with the flow elements of the flow-control module were resolved via an extensive in-house research and development effort at VACCO, a fully functional unit was completed and tested extensively in 2003, along with a second electronic control unit. The components were integrated into the XFS at Glenn in late 2003. This feed system (shown in the following photograph), was successfully used to control the anode flow during testing of a NASA 120M Hall effect thruster.

Xenon feed system (XFS) assembled with the VACCO-developed components and configured to operate the NASA 120M (2- to 3-kW) hall thruster.

Long description of figure. Photograph of the single-line xenon feed system assembled at Glenn that integrates all the components developed under this contract into a functional system. This feed system was used to control the anode flow into a NASA 120M Hall thruster that was installed in Glenn's Vacuum Facility 8 for characterization testing.

The final phase of this NASA Research Announcement was to resolve control issues that arose during thruster testing. This work was completed by VACCO and Aerojet RRC in April 2004. The completed hardware, along with the feed system, was delivered to Glenn in May 2004 for completion of this contract.

In conclusion, the ChEMS technology represents an important breakthrough in the size, mass, and cost of miniature fluid systems. The application of ChEMS technology to xenon flow control has resulted in a module ideally suited for electric propulsion applications. The ChEMS XFS provides system designers with a technology that allows them to realize the full potential of electric propulsion.

Glenn contacts: Timothy R. Verhey, 216–433–7458, Timothy.R.Verhey@nasa.gov; and David T. Jacobson, 216–433–3691, David.T.Jacobson@nasa.gov
Authors: Ben Otsap, Joseph Cardin, Timothy R. Verhey, Vincent K. Rawlin, Juergen Mueller, Randall Aadlund, Robert Kay, and Michael Andrews
Headquarters program office: OAT (Energetics)
Programs/Projects: Science Mission, In-Space Technology, Exploration Mission, Project Prometheus